Liquid Metal Nozzle Development
CFD Modeling

PFC/ALPS Meeting

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and the PMTF staff

Sandia National Laboratories

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for the United States Department of Energy's National Nuclear Security Administration
under contract DE-AC04-94AL85000.

OUTLINE

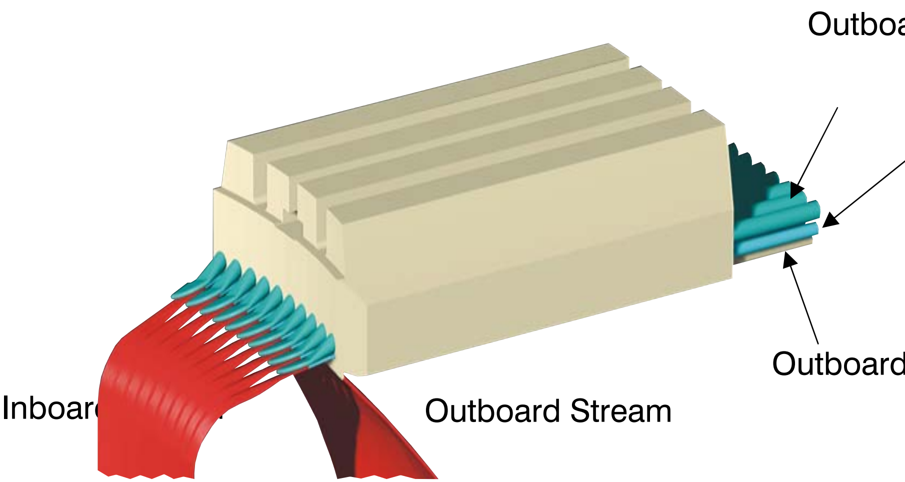
I. Comparison of nozzle performance with CFD

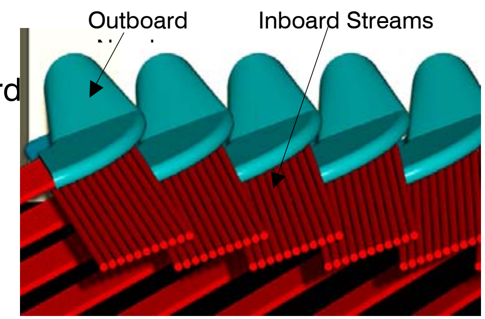
- Double compression nozzle
- Conic round stream nozzle
- Conic flat stream nozzle
- Flat-bottom flat stream nozzle
- Water testing – Lithium testing

II. CFD Modeling issues
CFD-2000 vs. Fluent

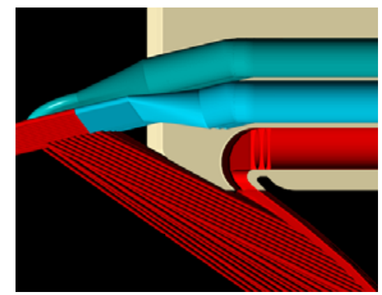
- Structured vs unstructured meshing
- k-ε model, validity to free surface
- VOF problems

PFCs: ORNL self-shielded nozzles

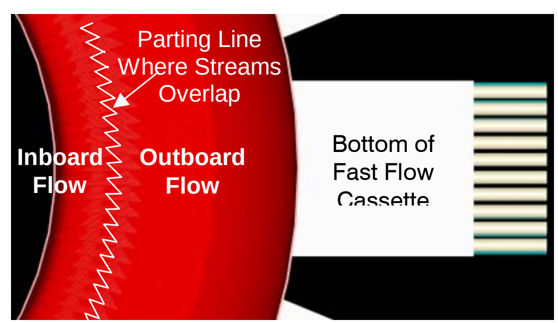




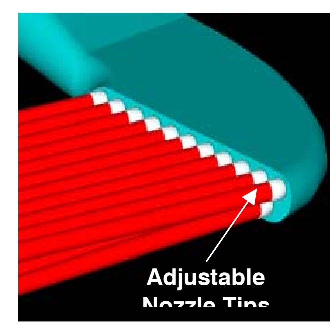
Front View of Fast Flow Cassette



Side Cutaway View of Fast Flow



Mid Plane Cut Looking Upward

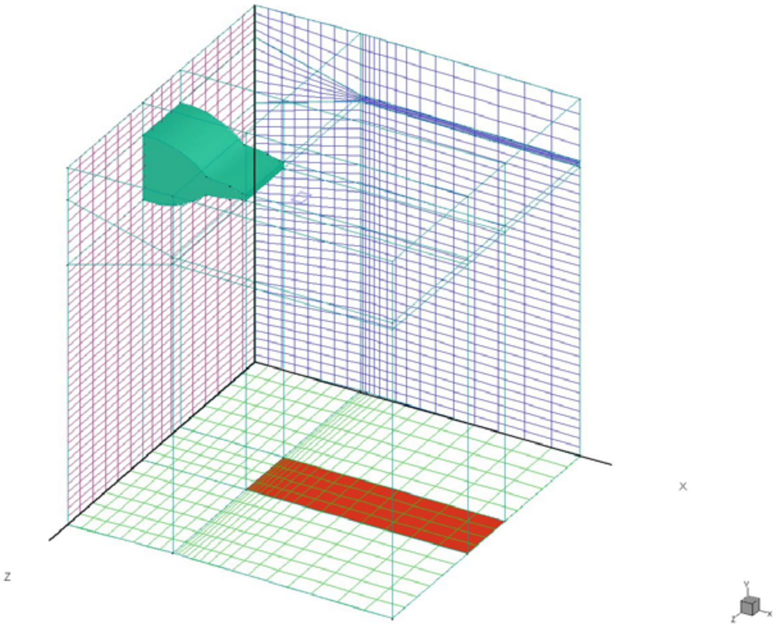


Outboard Nozzle

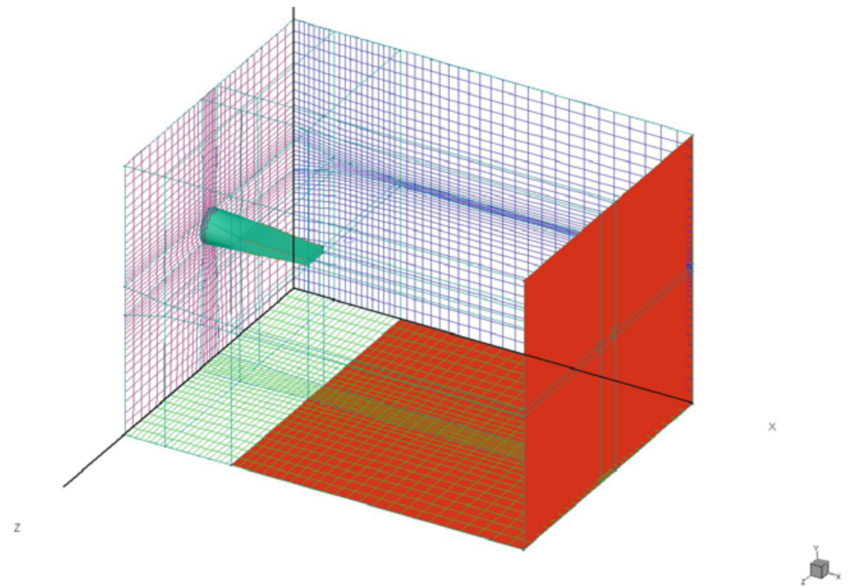
IFMIF and LIMITS nozzle models were created.

CFD-2000 Models

IFMIF double compression



LIMITS single compression



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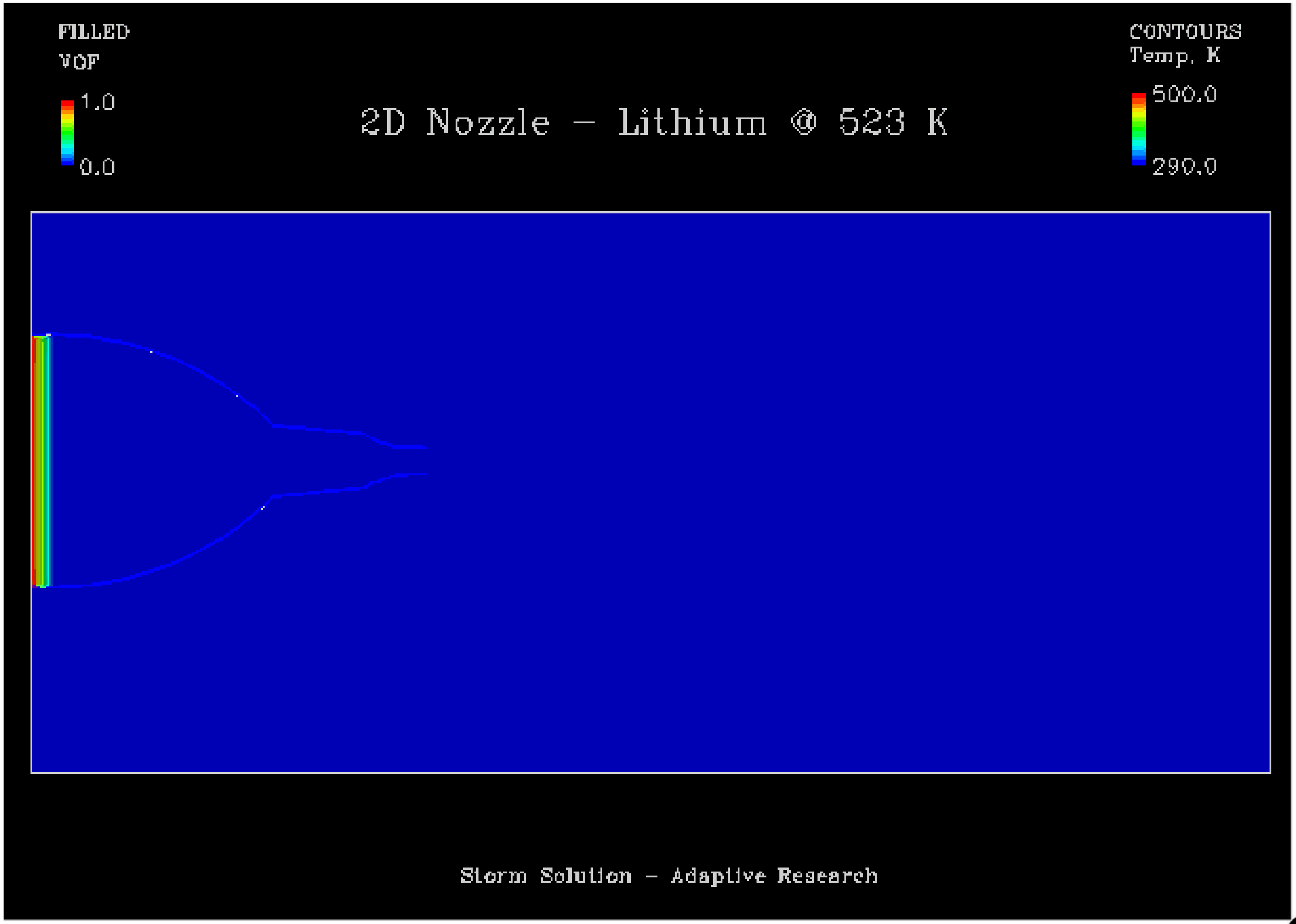
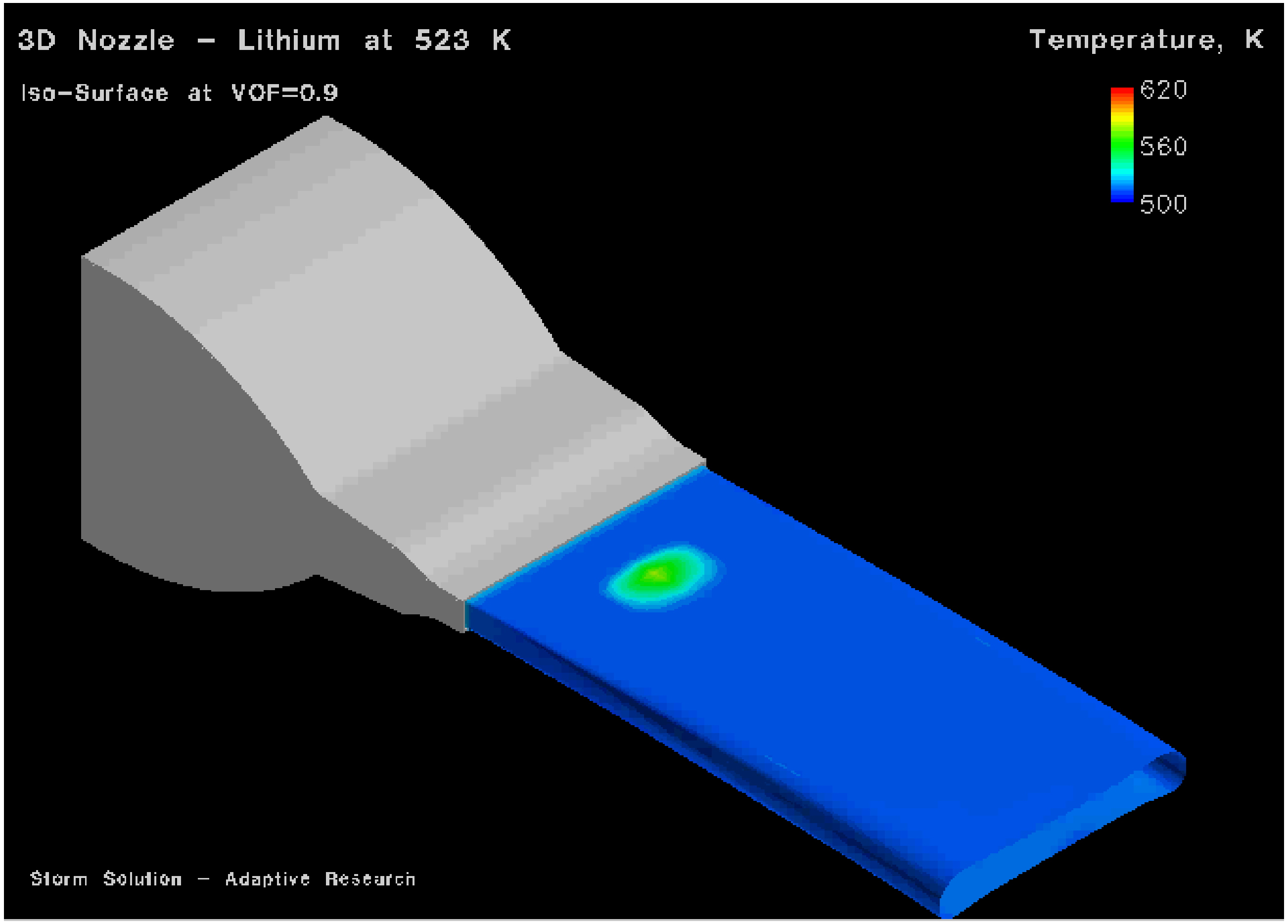
Double compression IFMIF nozzle
2-D simulation – 10 m/s



CFD-2000 modified for free surface heat flux



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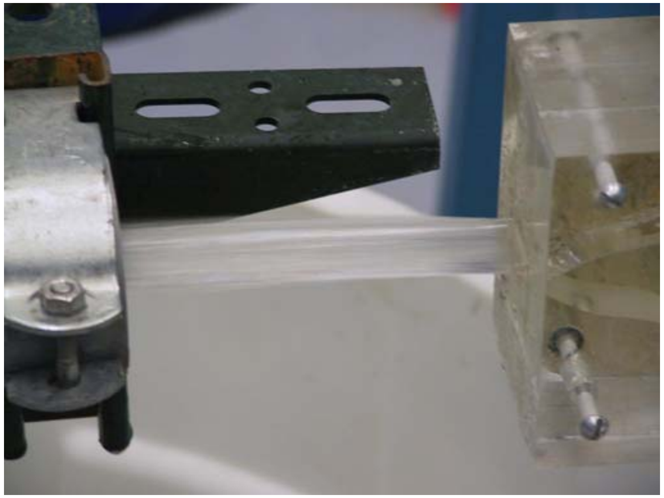
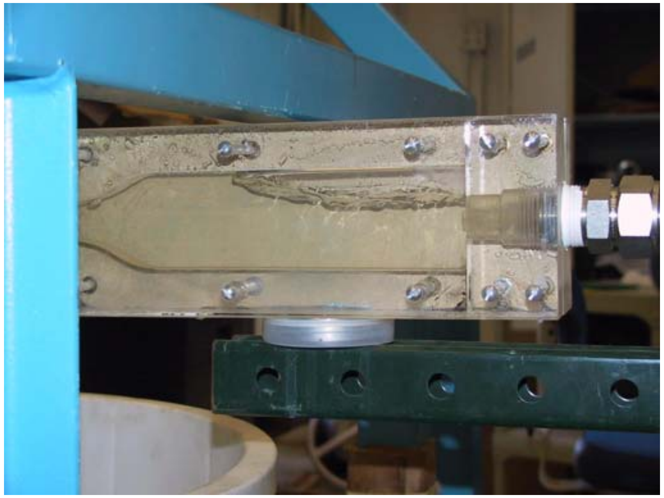
Plastic prototypes were tested with water.





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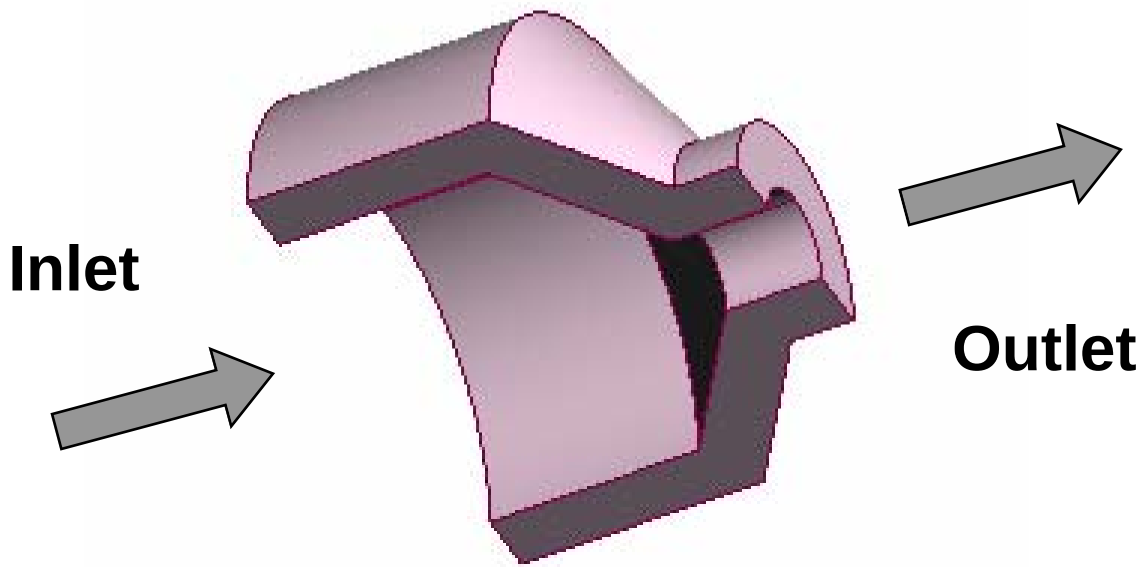
Round Stream Nozzle

- **Area Compression Ratio of 16**
- **Goal: prevent surface wave and droplet formation**



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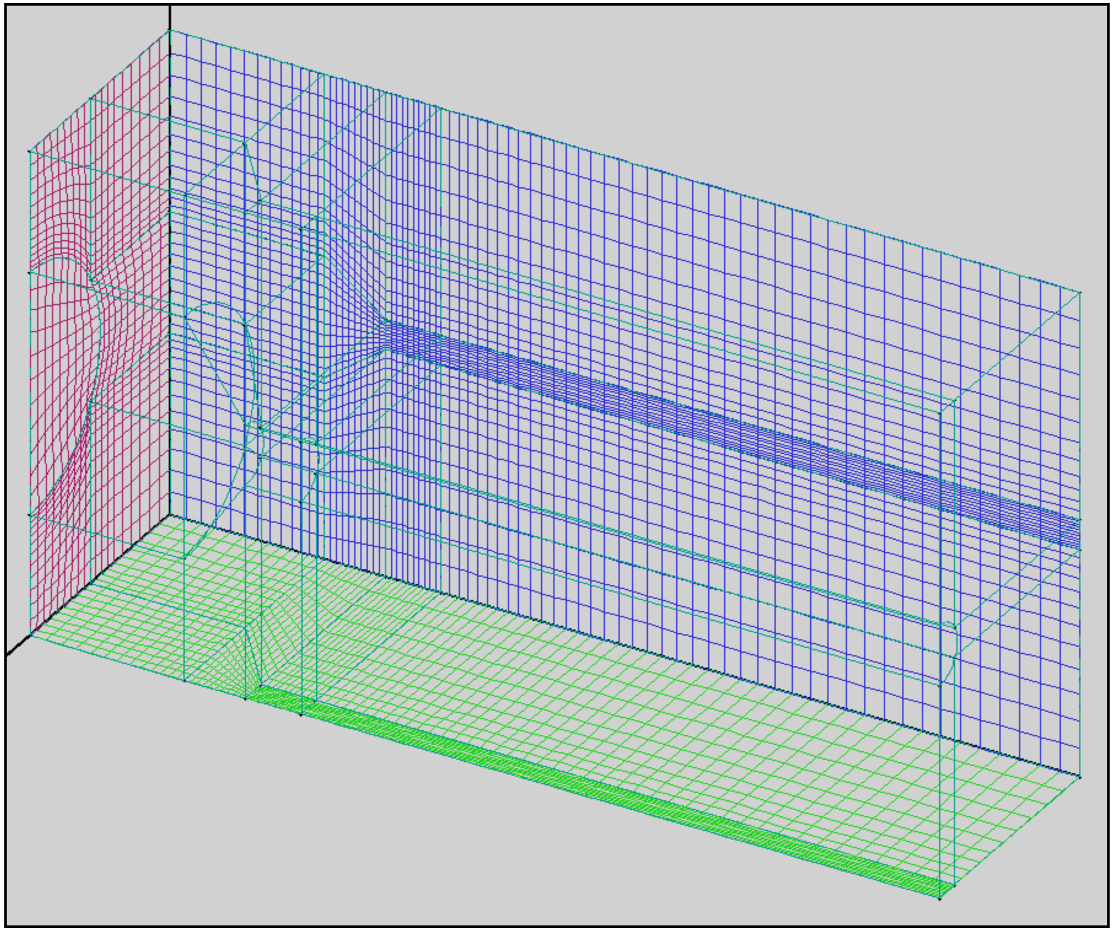
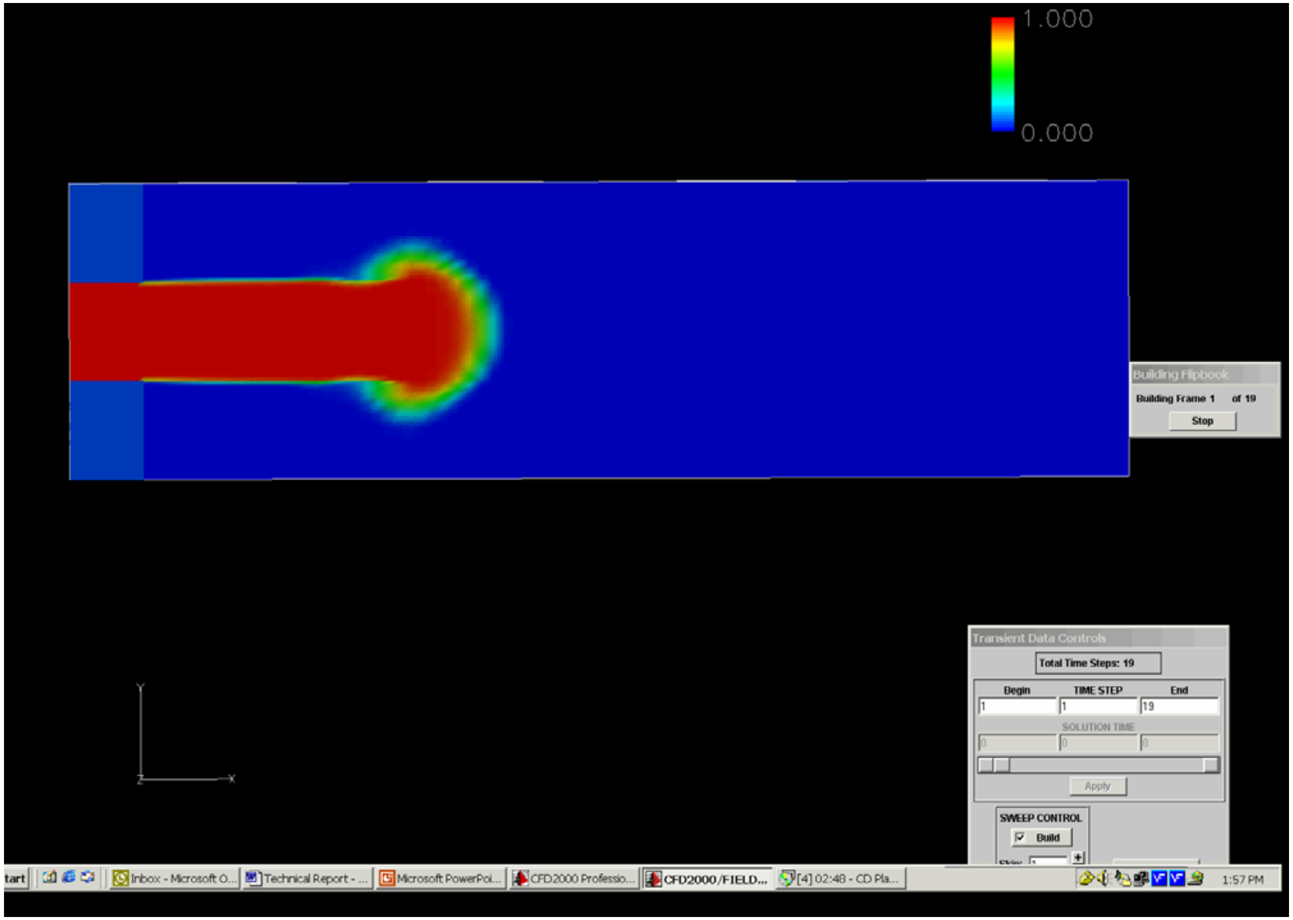
CFD-2000 structured mesh



CFD simulation predicts steady lithium flow.

- **Volume of Fluid of Liquid Lithium Flowing**



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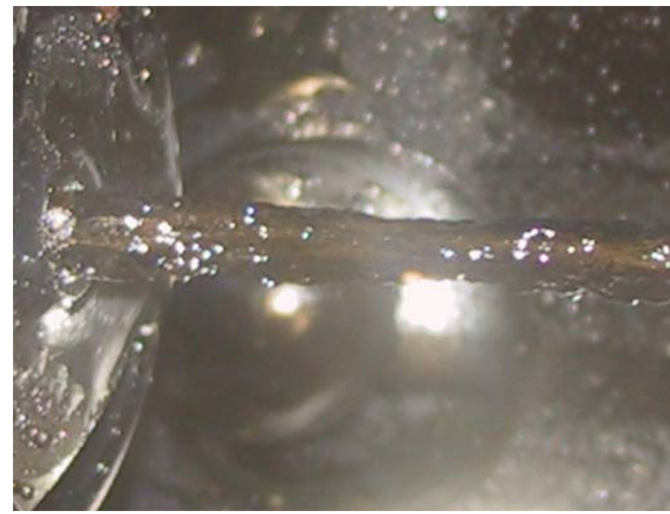
Nozzle was tested with water.

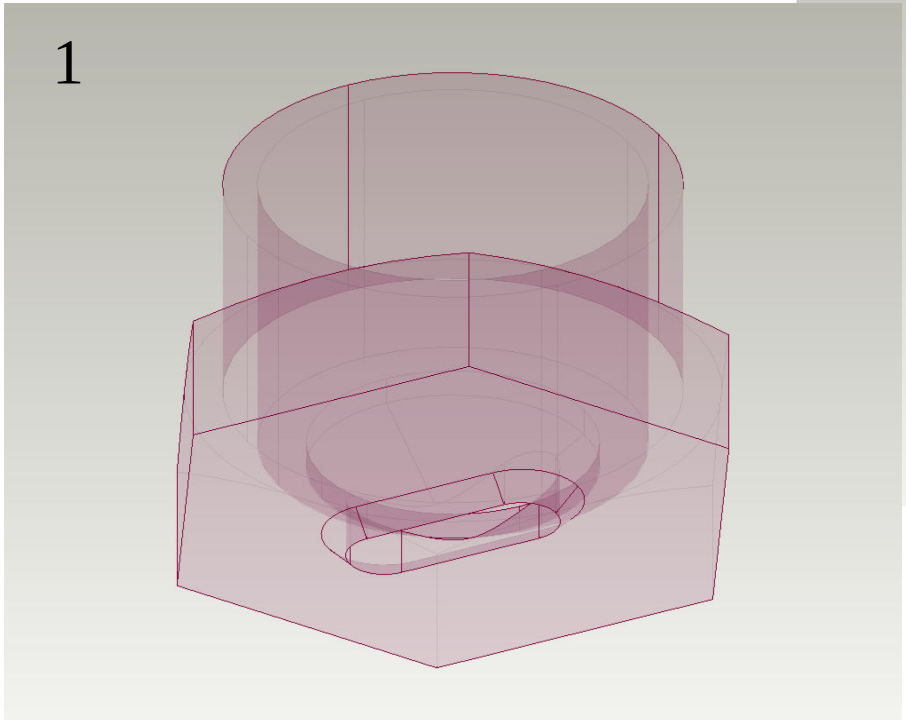
- 5mm Diameter Jet 200mm long
- Flow Velocity of 10 m/s
- Stable Fluting occurs on surface
- No droplet formation or break-up

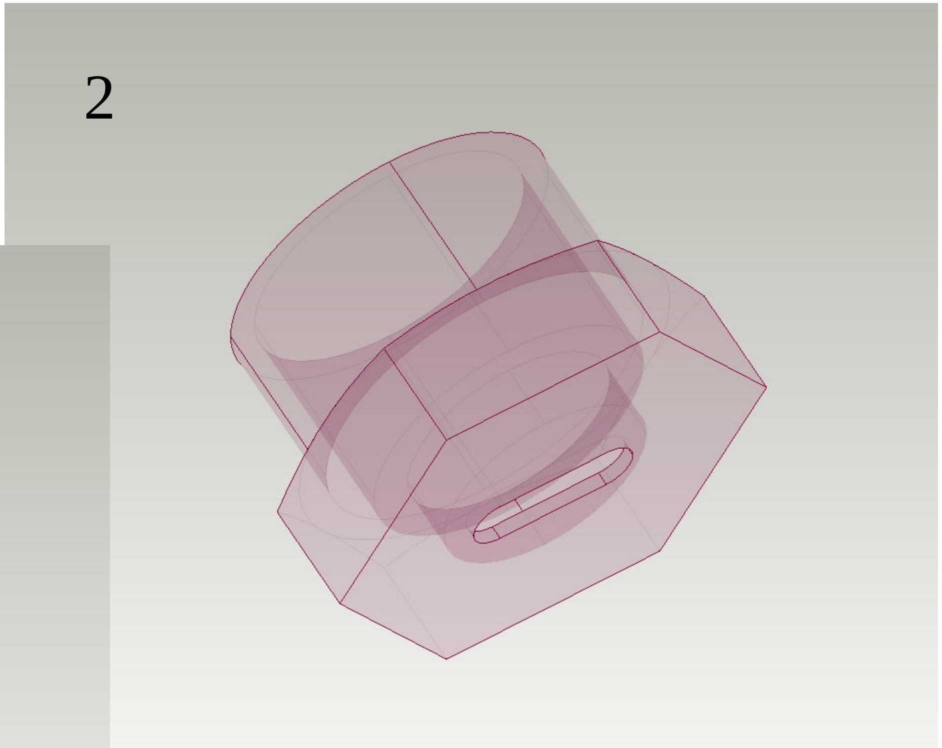
Nozzle produced lithium flow in LIMITS



Nozzles were machined from Swagelok endplugs.

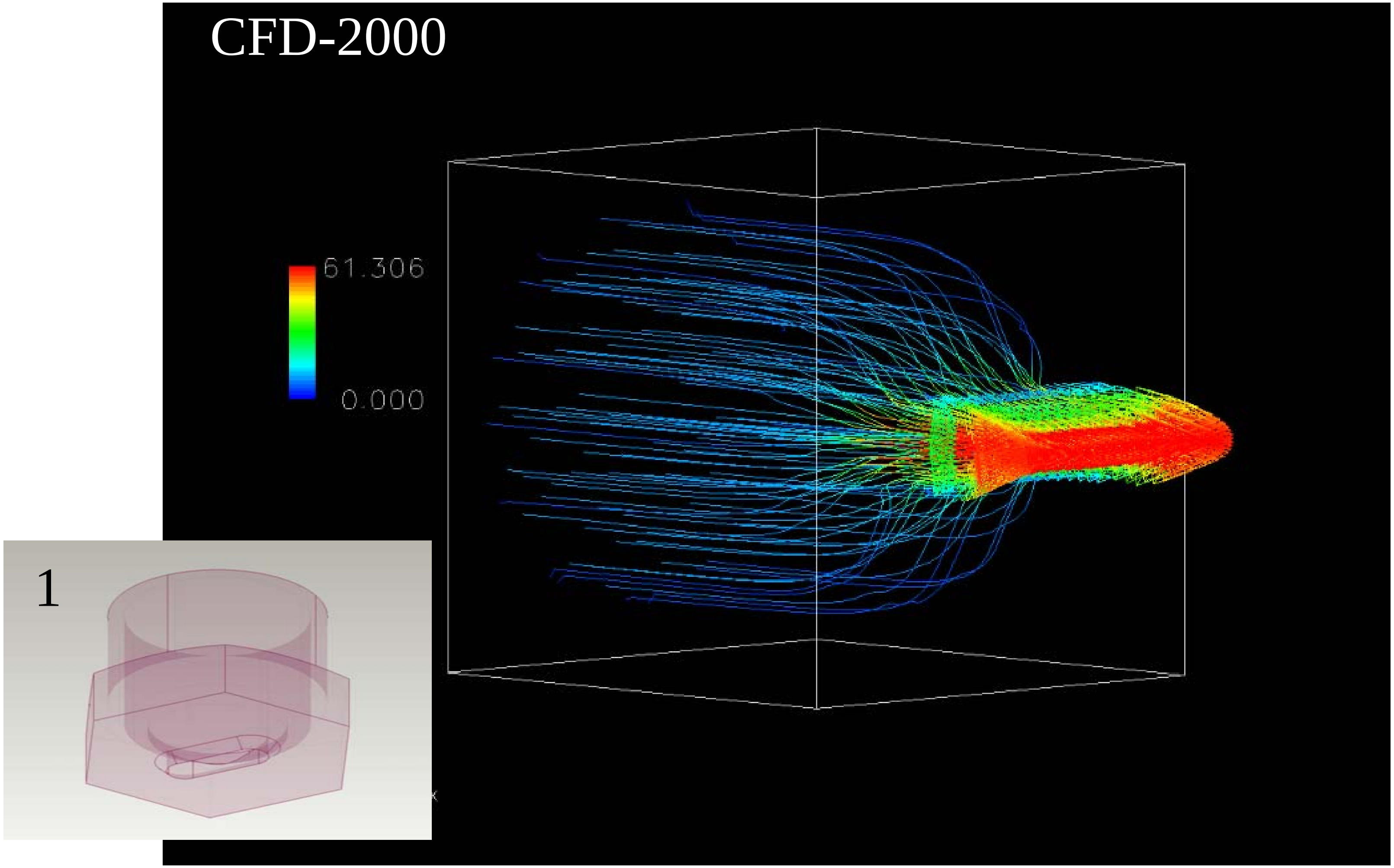
Conic section



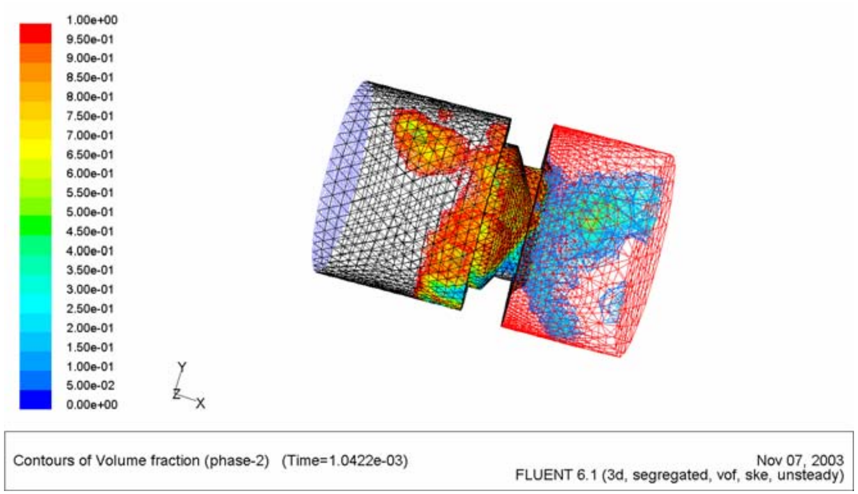


Cylindrical section

Conic nozzle simulation predicts stream behavior.

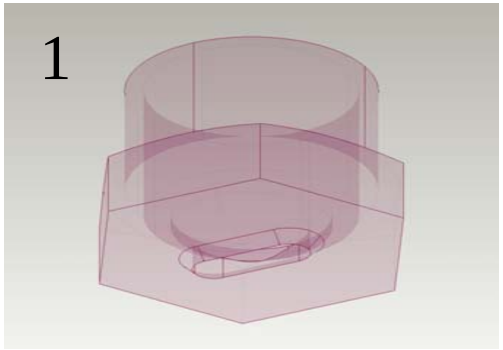


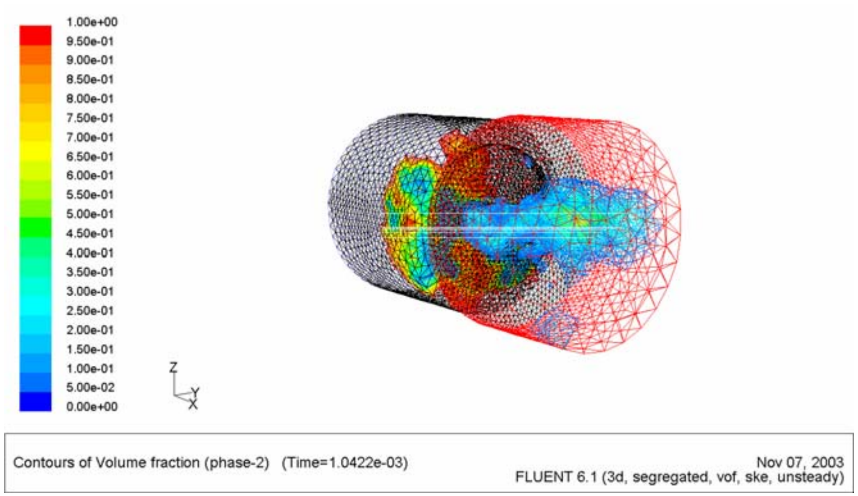
Lithium distribution at 1 ms for 1 m/s flow



Fluent

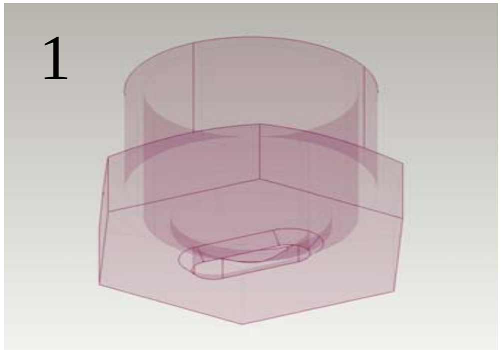
Conic section



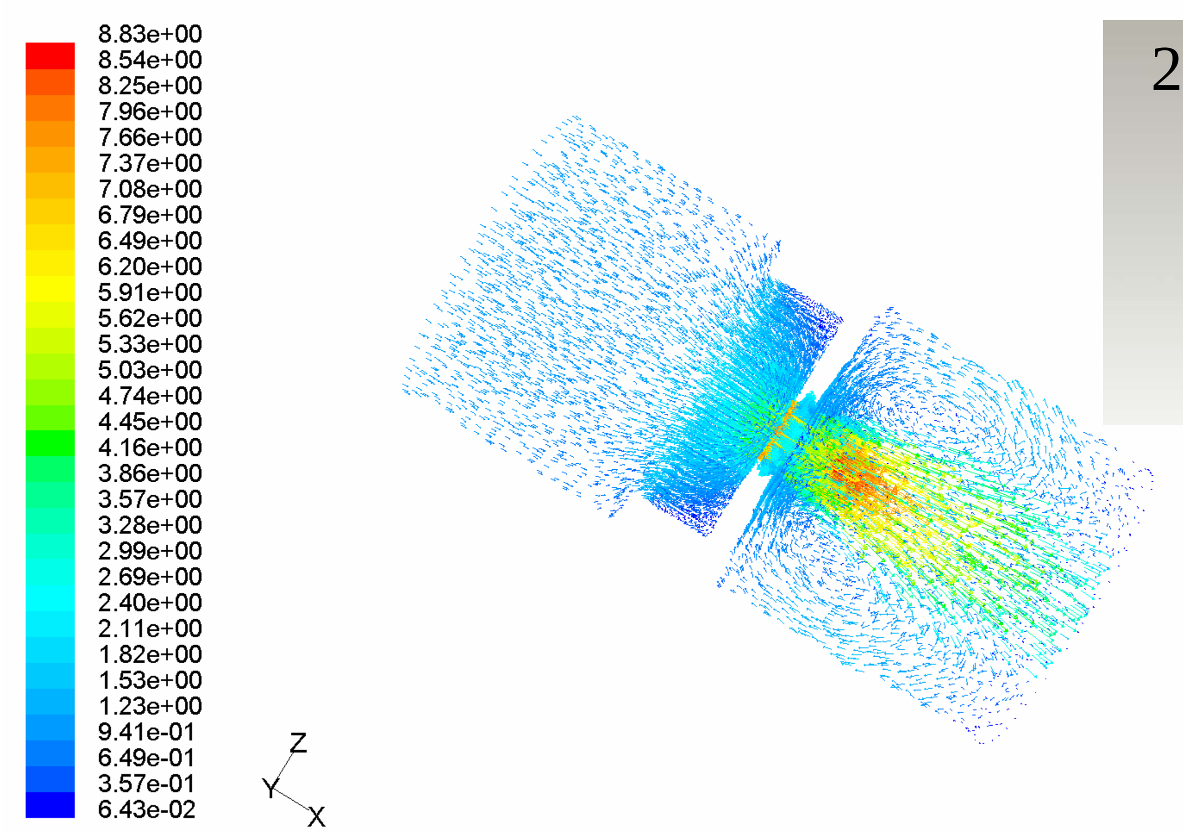


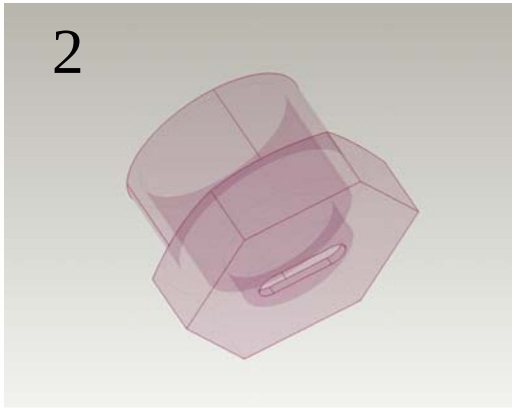
CFD results agree with water test

Conic section



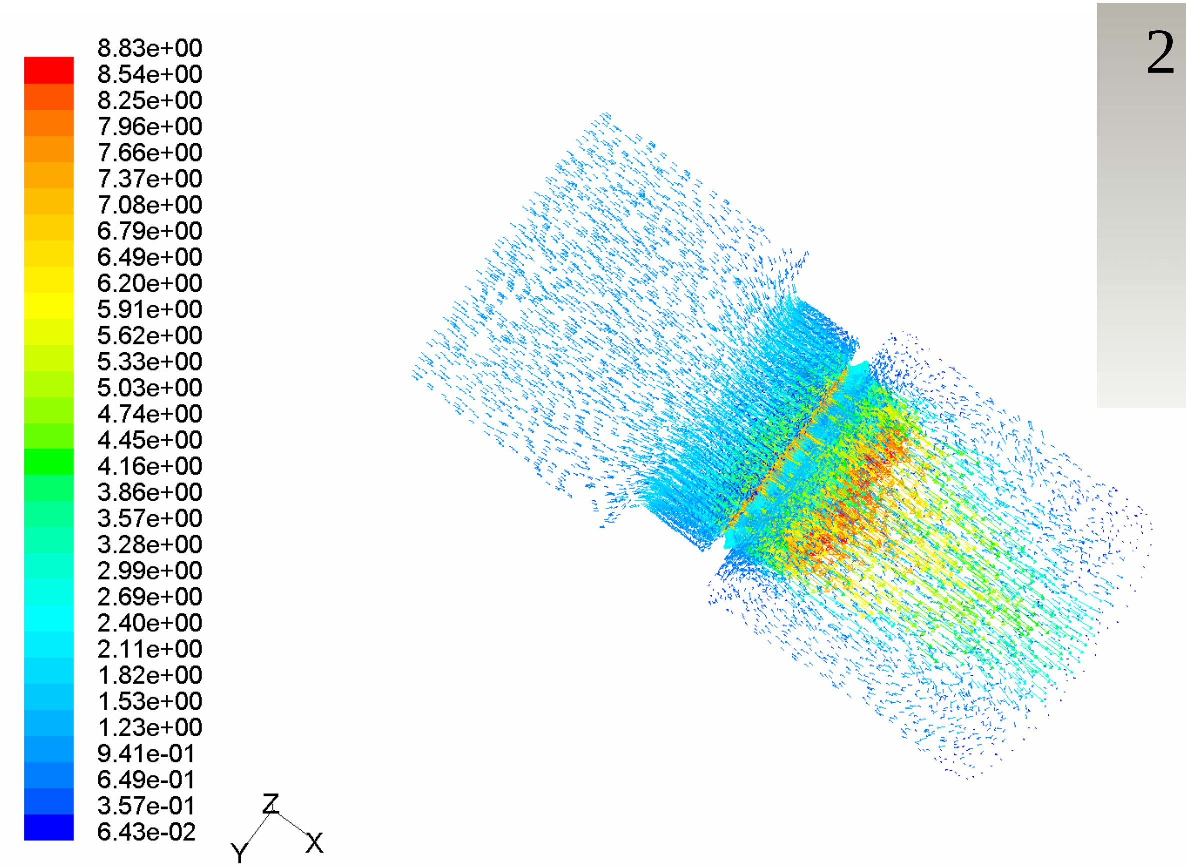
Flat-bottom nozzle is divergent along the minor axis.

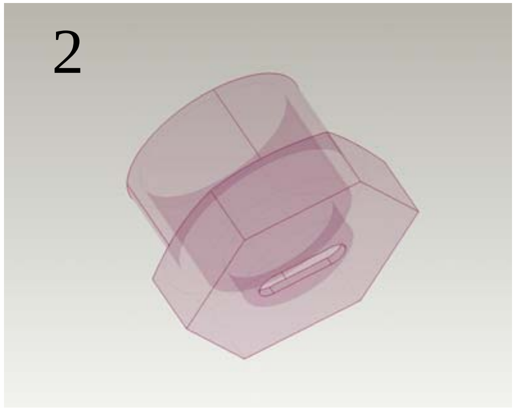




Velocity Vectors Colored By Velocity Magnitude (m/s) (Time=2.0410e-01) Nov 14, 2003
FLUENT 6.1 (3d, segregated, ske, unsteady)

Flatbottom nozzle is convergent along the major axis.





Velocity Vectors Colored By Velocity Magnitude (m/s) (Time=2.0410e-01) Nov 14, 2003
FLUENT 6.1 (3d, segregated, ske, unsteady)

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Cylindrical flat-bottom nozzle water test

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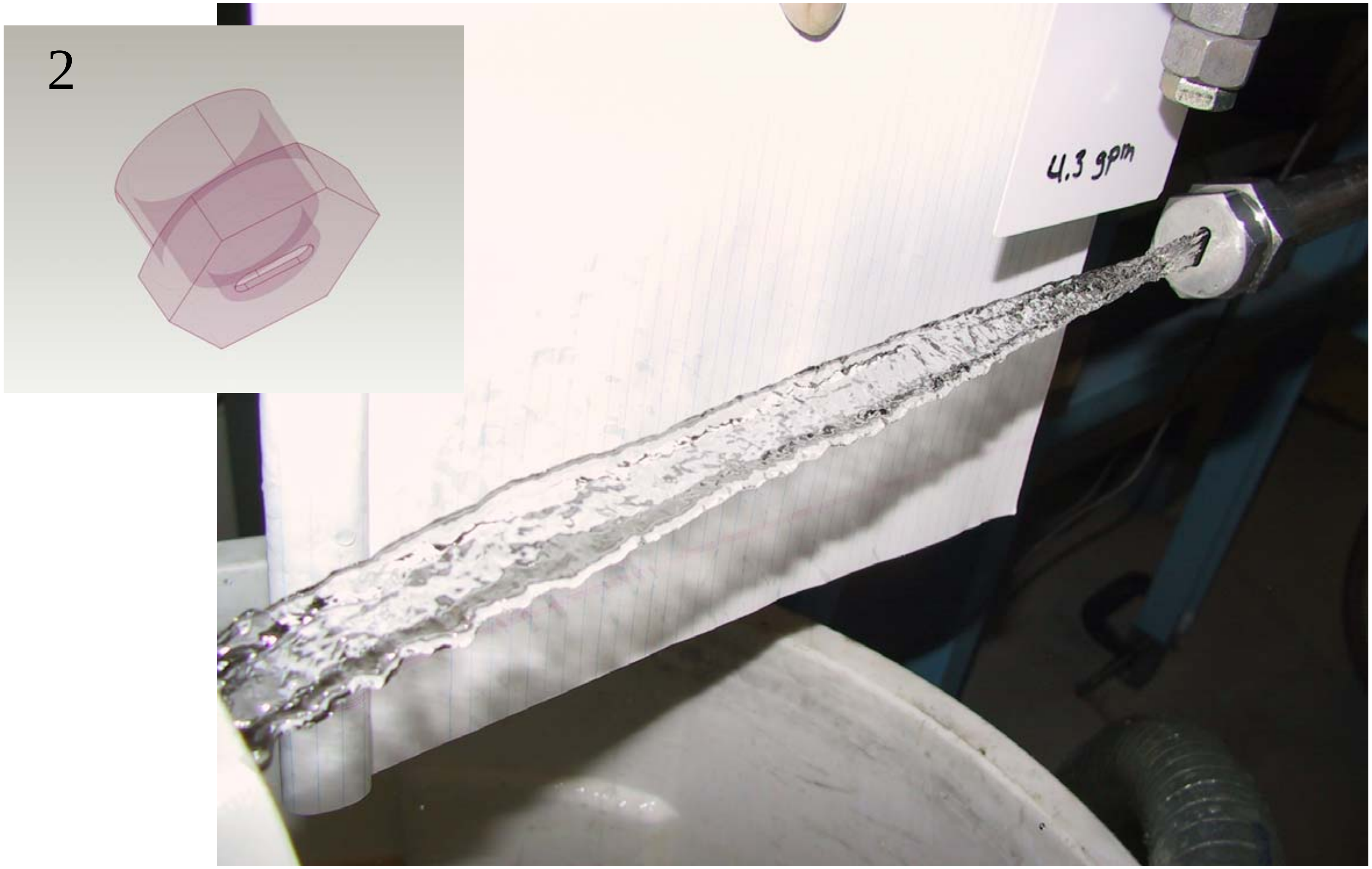


Structured vs Unstructured

CFD2000 4.11 – structured meshes

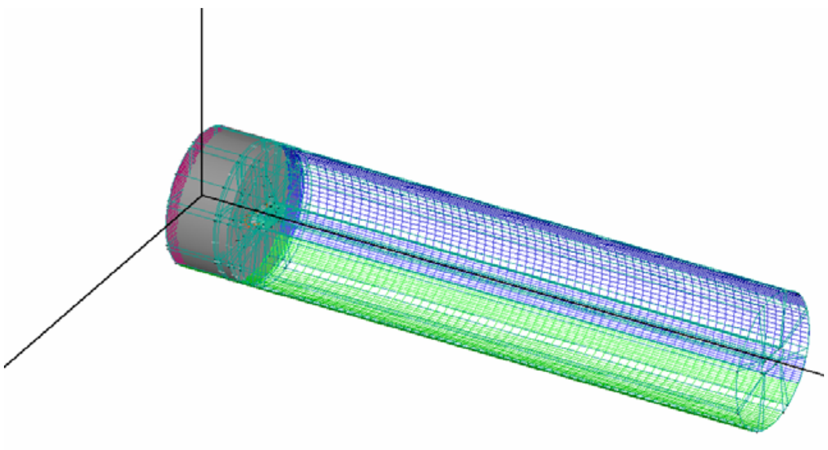
- **Complex 3-D nozzles are extremely difficult to decompose. (human intensive)**
- **No capability for CAD imports**
- **Fast solver (ijk indexed)**

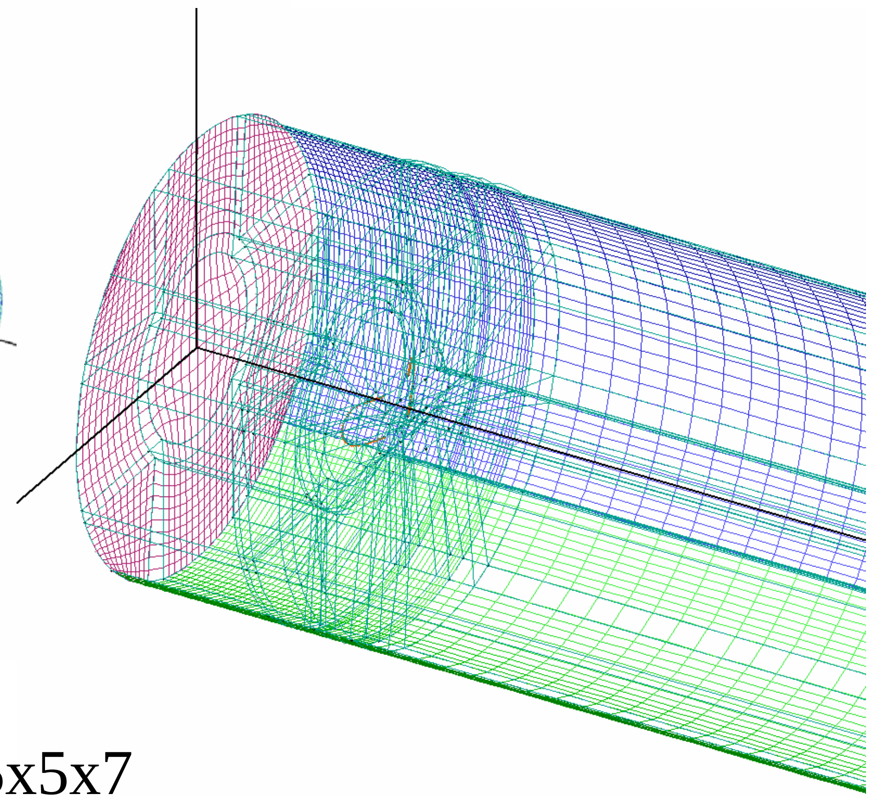
Fluent 6.1 – unstructured meshes

- **Easy CAD imports, quick setup**
- **No decomposition required**
- **Slow solver (computer intensive)**

3-d nozzle decomposition is labor intensive.

Curvature in all 3 dimensions



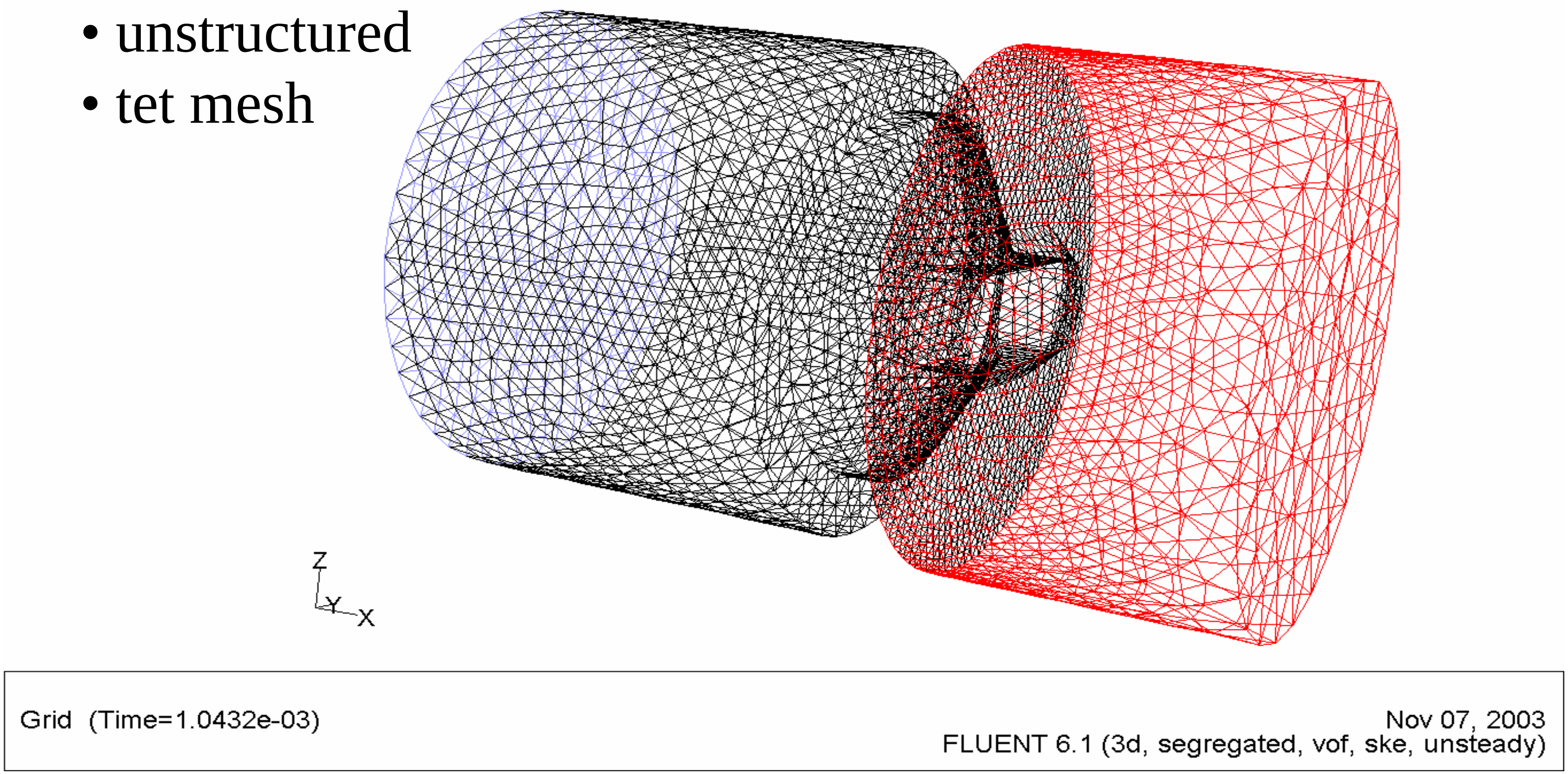


- manual build
- structured
- hex mesh

ijk: 5x5x7

conic flat stream nozzle

- easy import
- unstructured
- tet mesh



Turbulence modeling

Using standard k-ε model

- **Compression nozzles have instabilities in the turbulence dissipation, ε, resulting in divergence.**
- **Meshing – volume elements: inverted or poor aspect ratios.**
- **Standard k-ε not appropriate for near surface heat transfer.**

$$\mu_T = C_\mu \rho k^2/\varepsilon \qquad \kappa_T = \kappa/Pr_T$$

VOF formalism

- **Navier-Stokes breaks down below .1 atm. Vacuum cannot be modeled, only low pressure air.**
- **CFD-2000 modified for free surface heat flux.**
- **Fluent can perform free surface heat flux through user coding.**
- **Visualization and animation varies**
  - **Use FieldView for CFD-2000**
  - **Starting to use Ensight for Fluent**

Concluding remarks

- Off-the-shelf components may be useful for preliminary experiments (flow and HHF testing).

- Continue to develop a flat stream nozzle.

- For PFC applications, there appears to be no easy, inexpensive solution, even without considering the MHD issues.

- Systematic CFD design, prototyping and testing are required.

- Careful, innovative fabrication techniques are needed.